Development of a Platform for Expanding AUV exploRation to Longer ranges (PEARL)

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Renewable Energy

https://youtu.be/iYNBaOuZ8OM

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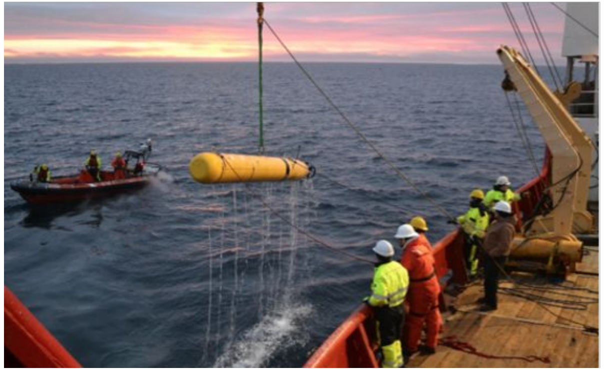
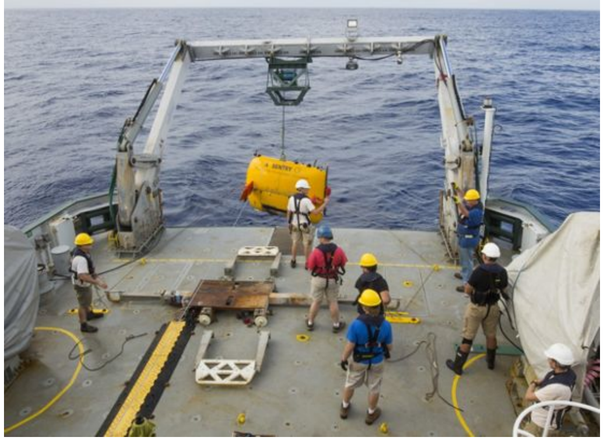
Introduction

- Challenges for Autonomous Underwater Vehicle (AUV)-based ocean exploration:
  - battery endurance, and
  - data transmission latency.
- Results in need for frequent recovery to recharge batteries and offload data, requiring a support vessel and crew, which can cost in excess of $30,000 per day [1-2].
- **Can we leverage new technology to reduce**
  - **operating costs - $/AUV mission hour, and**
  - **data latency?**





Traditional operations for recovering AUVs at sea.

[1] "MBARI—Rates for vessels, vehicles, MARS, labor, test tank," http://www.mbari.org/at-sea/mars-ship-rates/.

[2] Podder, et al., IEEE Int. Conf. Robot. Automat. 2004.

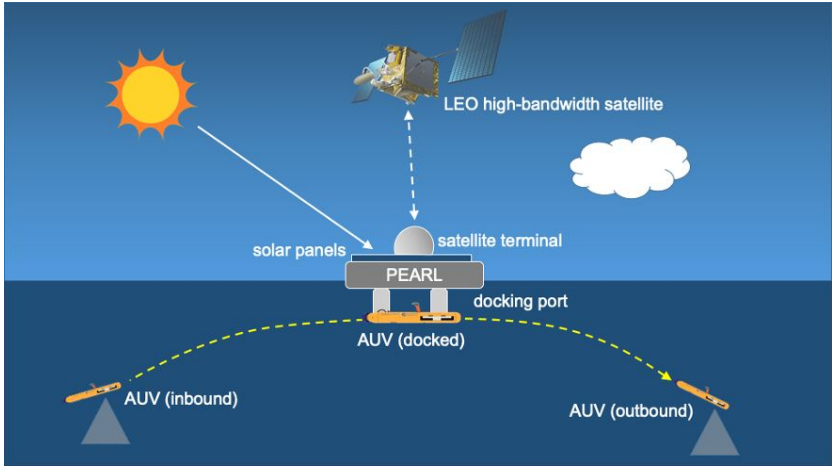
The Future of Ocean Monitoring?

Visualizing of global coverage via new satellite constellations.

- Classic low-Earth orbit (LEO) satellite networks: Iridium, Globalstar,Orbcomm
  - Low transfer rates,
  - Limited coverage
- New low-Earth orbit (LEO) high-bandwidth satellite Mega constellations: Starlink, Project Kuiper
  - Global coverage.
  - Transfer rates of 50-500 Mbps
  - Online as early as 2022
- Could enable **drastic changes in the way we do ocean science.**
  - Higher resolution ocean measurements
  - Near-real-time data

Objective

- **Goal**: **Extend the range and endurance of AUVs and allow for near-real-time data transmission by leveraging upcoming satellite mega constellations, thereby reducing operating costs via the Platform for Expanding AUV exploRation to Longer ranges (PEARL).**
- PEARL will provide AUV recharging via renewable energy and data uplink via a new generation of high-bandwidth low-Earth orbit (LEO) satellite mega constellations [3].
- Past docking, power, and data transfer platforms for AUVs limited in mobility, power generation, and range of vehicles serviceable.
    - PEARL aims to overcome these limitations.



An inbound AUV can dock to PEARL, which simultaneously charges the vehicle using renewable solar energy, and offloads data via a high-bandwidth LEO satellite link, enabling the AUV to conduct longer-range missions and collect higher resolution ocean measurements.

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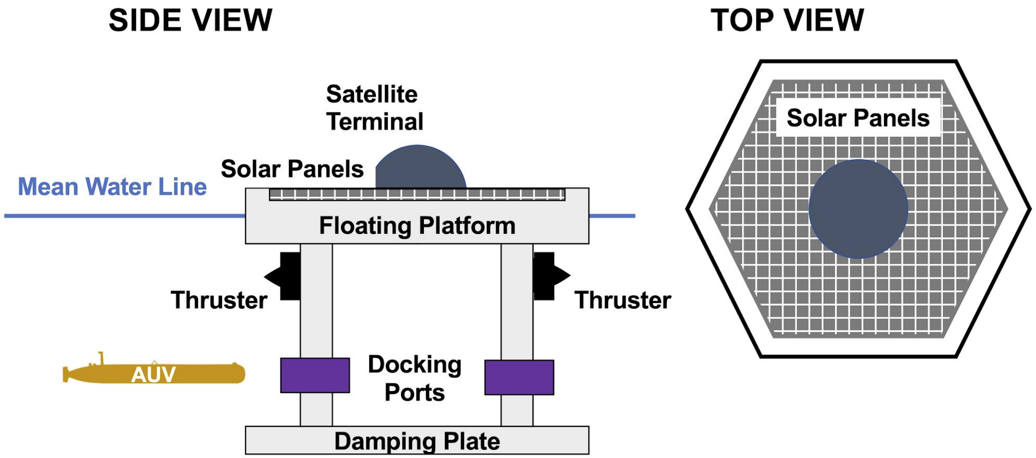
[3] Foreman et al., AIAA SPACE and Astronautics Forum 2017.

PEARL Design Overview

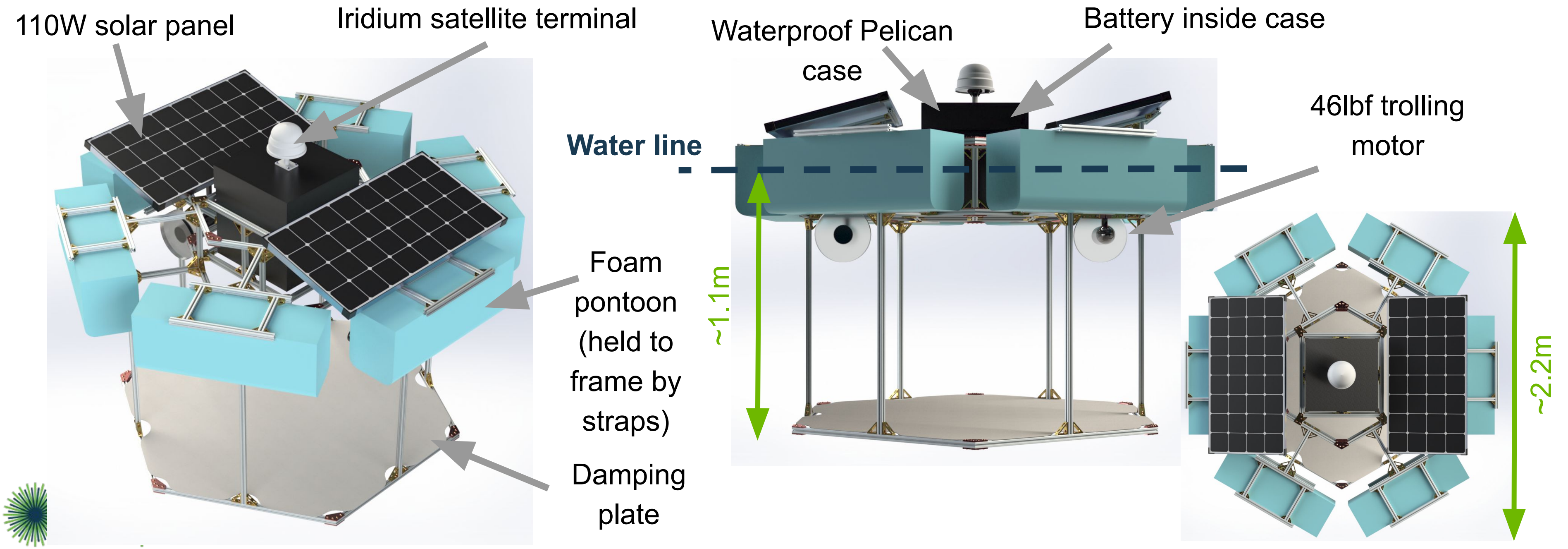


Conceptual design of PEARL.

- PEARL consists of an upper floating platform and a lower damping plate, connected by a structural spar.
- Floating platform houses solar panels and a satellite terminal, and could be shaped like a hexagon to enable multiple servicing platforms to connect together for increased power and data transfer capabilities.
- Submerged damping plate reduces heave motion of the platform.

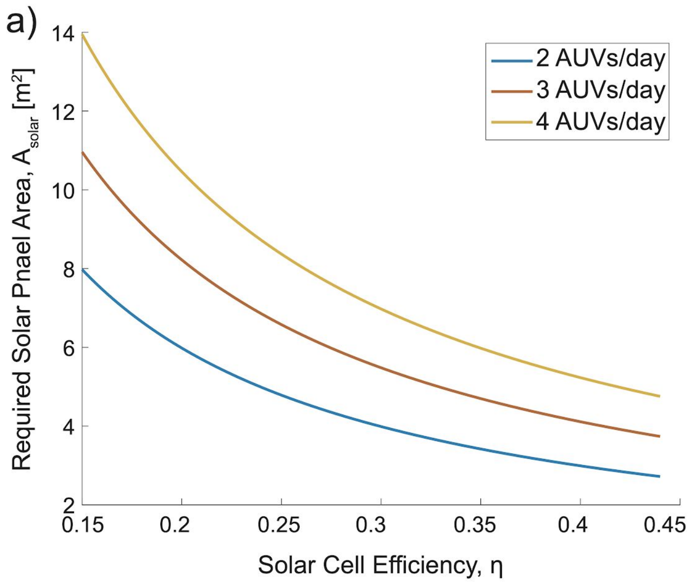
PEARL Ocean Prototype

- 1:2.5 Froude-scaled prototype of PEARL was developed for ocean testing.
- **Goal: Investigate concepts energy harvesting, data collection, and data transmission.**



Highly coupled design: energy generation

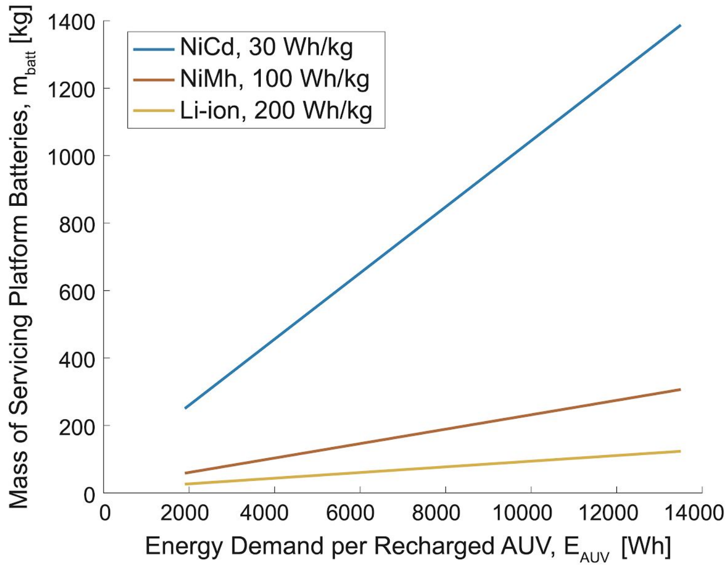
- Size and efficiency of the solar PV panels determines the amount of power that can be collected and stored onboard.
- Figure shows trade-off between size and efficiency of solar PV panels for different scenarios of AUVs charged per day.
- Trade-off results are for a baseline case with a servicing platform power consumption of 50W, AUV energy storage capacity of 1.9kWh, and an incident solar flux of 800W/m^2 at an average incidence angle of 55°, with typical electrical conversion inefficiencies and lifetime degradation. Appropriate depth of discharge values were chosen for the various battery chemistry to ensure a 10 year cycle life.



Highly coupled design: energy storage

- Battery chemistry dictates the recharge rates of AUVs, and number of recharge cycles to be supported.
- Figure shows trade-off between energy demand and mass of servicing platform for a variety of battery chemistries.
- Trade-off results are for a baseline case with a servicing platform power consumption of 50W, AUV energy storage capacity of 1.9kWh, and an incident solar flux of 800W/m^2 at an average incidence angle of 55°, with typical electrical conversion inefficiencies and lifetime degradation. Appropriate depth of discharge values were chosen for the various battery chemistry to ensure a 10 year cycle life.

b)



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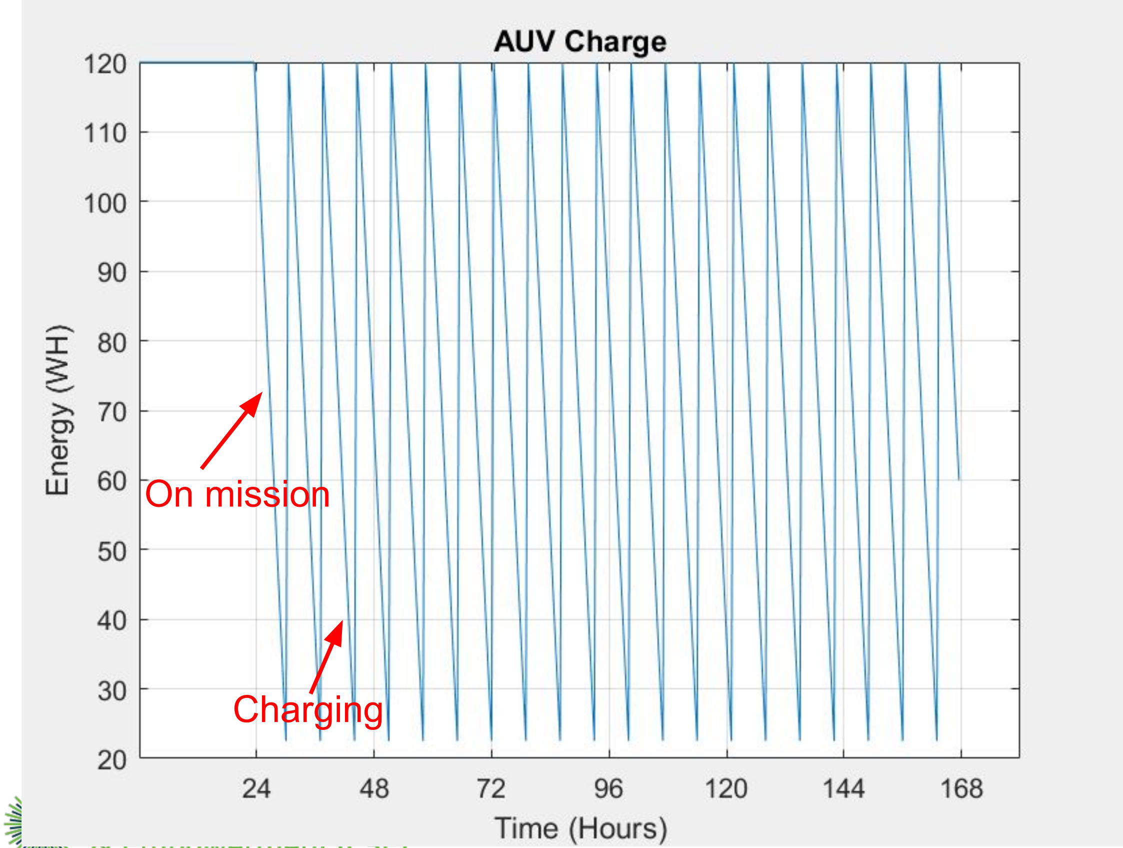
Key function: recharging AUVs at sea



- Figure shows AUV charge level modeling.
- AUV Returns to platform for recharge @ 20% battery capacity
- Assumes:
  - 30 minute charging
  - 8 hour discharging (mission)
  - Linear charging and discharging
- AUV dormant during first 24 hours for platform charging.
- If platform battery levels are too low, AUV will be charged directly by solar panels.

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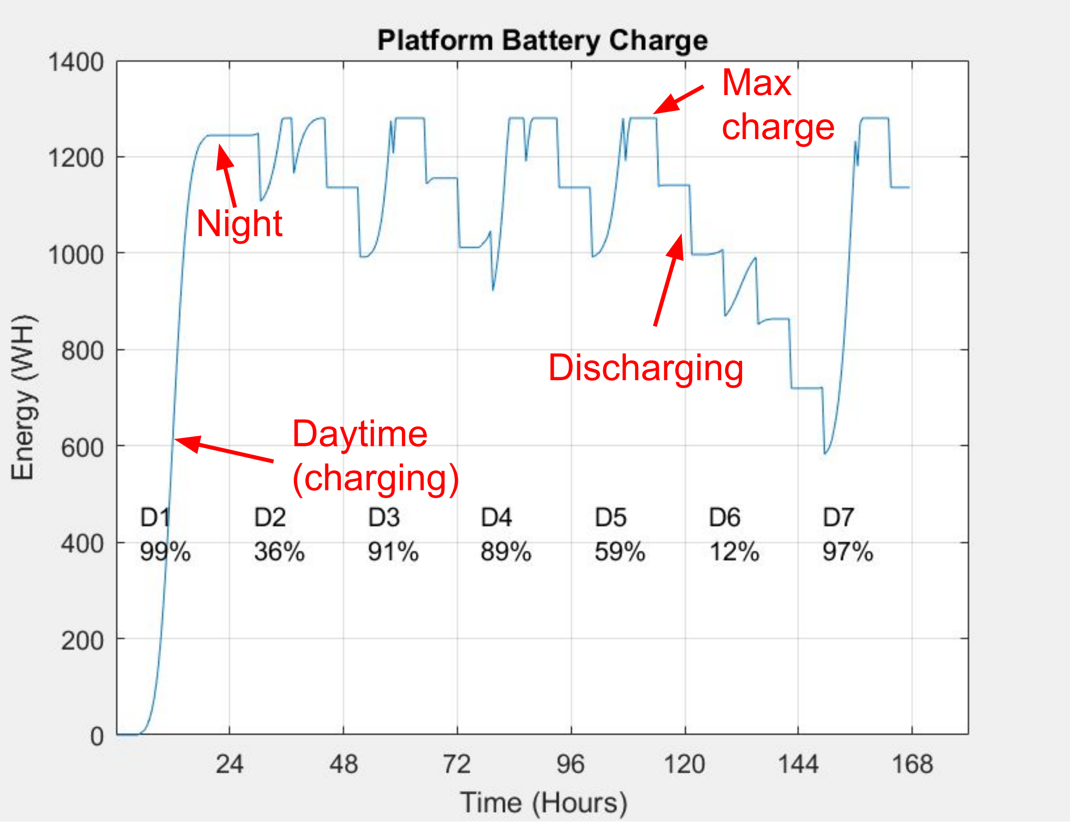
Energy management is a key challenge

- Figure shows model the predicts platform charge levels.
- "D#" indicates day. "YY%" indicates amount of sunlight available (based on weather)
    - Solar panels charge platform (assume 20% loss)
    - When at 100% charge, solar panels disconnected
    - AUV charging discharges platform

- Key issue: platform could discharge due to poor weather conditions, requiring AUV to dock for long periods.



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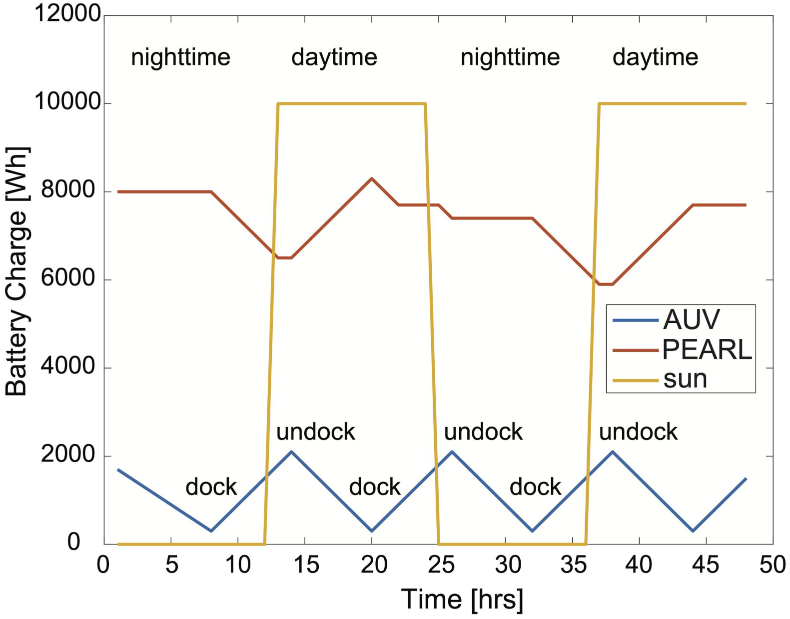
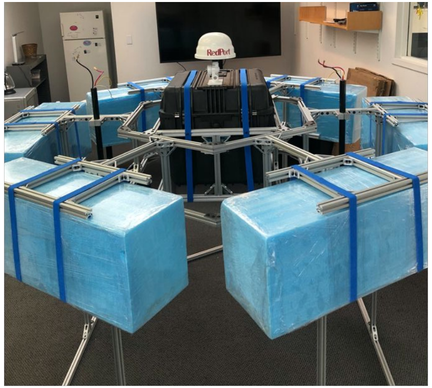
Behavior coordination needed

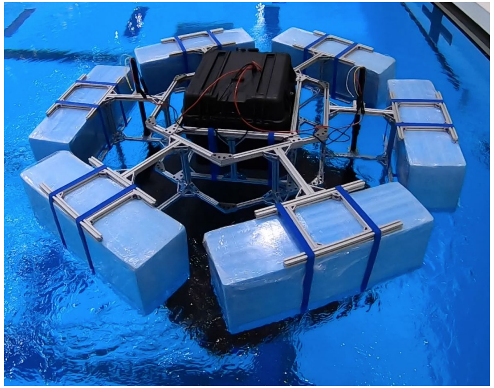


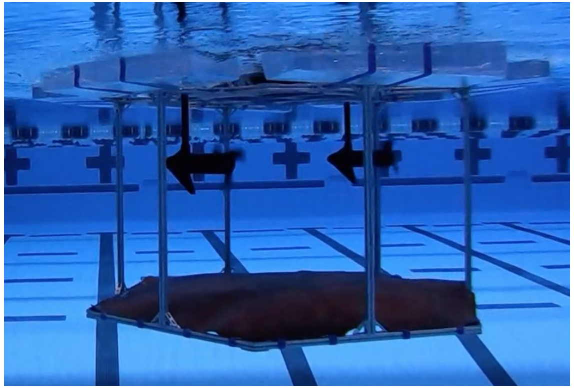
- Is there an optimal scheduling and coordination of underwater, surface, and space assets?
- Figure shows discrete event simulation of system-of-system over 48-hour mission cycle.
- t = 0: AUV fully charged (1.9 kWh) and batteries deplete at a rate of about 200W. PEARL fully charged (8000 Wh).
- t = 8 hours: AUV reaches maximum depth of battery discharge (300 Wh) and docks with PEARL. AUV charges at rate of 300W. Since it's night, PEARL battery charge decreases at same rate.
- t = 12 hours: sun rises and discharge of the PEARL battery flattens out since the sun starts recharging PEARL via its built-in solar panels.
- t = 14: AUV full charged and undocks. PEARL battery charge increases since it is daytime (assuming no cloud cover) and there is no load.
- Simulation predicts 4 dives of 6 hours each during the 48-hour period → a productivity of about 50%.

Continued and Future Work

- Fabrication, and assembly of prototype complete.
- Pool testing of flotation and manual motor control complete.
- Ocean test of platform to begin 10/17/2020.
- Sensors onboard PEARL allow monitoring of ambient light intensity, solar energy harvested, battery charging/discharging, and load power draw.
- **Ocean trials of prototype will seek to validate model that predicts energy state of PEARL and a paired AUV** given ambient light intensity, characteristics of solar PV cells, and load**.**







Images of prototype fabrication and pool testing.

Acknowledgments

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